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A THRUST-TORQUE DYNAMOMETER INCORPORATING HYDROSTATIC MOTOR SUPPORT

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INTRODUCTION

The National Aeronautics and Space Administration's Langley Research Center has developed and is continuing the improvement of the Scout Research Vehicle, the first all-solid-propellant vehicle proven to have orbital capabilities. During the Scout flight program several unusual phenomena have been discovered, which have led to further investigation. One of these was the apparent self-induced torque developed by the third-stage motor. Langley Research Center vehicles other than the Scout utilize fins or spinning for stabilization which may mask any induced torque tendencies existing in these motors. Thus any roll which has previously been experienced was intentional or attributed to a misalinement of the fins. When it was found that the X-254 motor rolled in an environment where no appreciable external forces existed, it was decided to investigate this phenomenon in a static test environment where there would be no external forces to consider.

The objectives of this research program are to construct an apparatus which would:

1. Accurately measure the self-induced torque tendencies of a rocket motor

2. Be sufficiently versatile to accommodate many sizes of rocket motors

3. Require a minimum set up time

4. Supply the above-mentioned torque data without sacrificing accuracy in obtaining rocket ballistic data

Rocket motor self-induced torque was first detected during the flight of ST-1, when the control system designed to correct up to approximately 10 foot-pounds of torque was overpowered and the vehicle rolled as much as 210° before this effect subsided. This is equivalent to a maximum torque of 18 foot-pounds. For the ST-2 flight, the control system's capacity was increased to 56 foot-pounds and, as a result, the vehicle roll was restricted to $\pm 2^{\circ}$ corresponding to a maximum torque of 10 to 12 foot-pounds. The third stage of the Scout vehicle is the high-performance, fiberglass plastic, 2,300-pound Antares X-254, A-1 motor shown in figure 1. This motor evolved from the 500-pound X-248 motor (very similar in case construction) originally developed for Vanguard third-stage propulsion.

A cast double-base propellant designated BUU is employed in both the X-248 and X-254 rocket motors. This propellant is only slightly aluminized as contrasted with 16 to 20 percent usually found in high-impulse systems. The propellant port configuration is a single perforated tube, slotted near the nozzle end to yield sliverless burnout. Static firings have shown that both of these motors exhibit very high vibration levels indicating combustion instability. As in the X-248, the X-254 has a paddle shaped similar to a tuning fork located within the combustion chamber to suppress resonance and unstable burning to acceptable levels. Post fire inspection of the paddles in X-254 motors statically tested at A.E.D.C. revealed that the paddles were twisted. It is significant to note that the paddles were twisted in the same direction as the direction of roll of the Scout vehicle.

In order to investigate this problem, a dynamometer was designed, fabricated, and tested to measure accurately the ballistic properties of a rocket motor with up to 12,000 pounds of thrust while simultaneously measuring roll in either direction. Also, with this design, complete vibrational data can be taken during static firing in order that the tendency to roll can be compared to the vibrational levels. This paper will describe primarily the design and operation of the dynamometer. Typical results attained with this apparatus are included.

DESCRIPTION OF DYNAMOMETER

The thrust-torque dynamometer is designed to adapt to the existing LRC thrust stand which is shown in figure 2. This existing stand is capable of handling motors up to 40 inches in diameter and thrust levels up to 50,000 pounds.

When the dynamometer is added, the existing motor supports shown in figure 2 are replaced by the much larger motor support rings of the dynamometer as shown in figure 3.

In addition to these motor support rings, the dynamometer consists essentially of a conical thrust adaptor, several radial and axial hydrostatic lift pads, a torque arm, and a continuous-flow oil-pumping system.

As shown in figure 3, there are three radial hydrostatic lift pads equally spaced around both fore and aft motor flange mounting rings. In operation, the six radial lift pads at the end rings restrain the motor against movement in the lift, side force, yaw, and pitch directions while leaving it free and essentially frictionless in the thrust and roll directions.

Two axial lift pads located in front of the conical-shaped thrust adapter transmit the thrust forces to a strain-gage load cell while leaving the motor free to roll.

An idea of the principle of operation of the lift pads may be obtained from figure 4. Oil from the external pumping system enters the center cavity of the lift pad through a flow adjustment valve, fills the cavity, and exits under the closely fitting land around the periphery of the pad. At zero applied load, zero pressure is required in the cavity to maintain equilibrium, therefore the oil forces the pad upward until a relatively large gap under the land is reached. At this time the pressure drop from the cavity to the atmosphere approaches zero; the entire drop from supply pressure to atmospheric will take place across the valve. As a load is applied, pressure is required in the cavity to maintain conditions of equilibrium. The gap at the land decreases and pressure in the cavity builds up. The total pressure drop from supply to atmospheric is now divided between the valve and the restricted passage through the gap; therefore, flow has decreased. At maximum capacity load the gap has decreased to the point that local irregularities in the surfaces at the gap begin metal-to-metal contact and frictional resistance to lateral movement begins.

The pads possess limited capacity to sustain overturning movements through redistribution of the pressure drops along the restricted passage at the gap; the spherical seats are designed to keep friction moments within this limit.

ASSOCIATED EQUIPMENT AND PRE-TEST CHECKOUT PROCEDURE

The dynamometer is equipped with a 1/2-pound electro-dynamic shaker, which applies a known torque at a known frequency to the system. An SR-4 strain indicator was attached to the 50-pound cell which was used to measure the torque. Using the SR-4 strain indicator in conjunction with the shaker, an indication of the freedom of the system could be obtained. When it was repeatedly indicated that the dynamometer was free, the system was calibrated by placing 2-pound weights on pans located on either side of the rocket motor. The shaker continues to run throughout the test and is monitored up until approximately 1 minute prior to start of test.

PRELIMINARY SYSTEM TESTS

An initial system check was made by measuring the thrust of a Thiokol Cajun rocket motor while external torque was applied to it, as shown in figure 5. An Atlantic Research Company 0.6KS40 rocket motor was mounted perpendicular to and approximately 6 inches from the Cajun thrust axis, on a ring attached to the motor support ring. By firing the 0.6KS40 while the Cajun was thrusting, a known torque was introduced into the system. The results of these tests are shown in figure 6. It can be seen that the torque time history of the 0.6KS40 when fired while mounted on a Cajun motor thrusting and on an inert Cajun compares favorably with the torque time history computed from 0.6KS40 nominal thrust time data.

Based on the results of these preliminary system checkouts the X-254 motor was mounted in the dynamometer in preparation for static testing. The system was calibrated as previously described and the test was successfully conducted.

Typical data obtained with this dynamometer are given in figure 7, showing thrust and torque versus time for the X-254 motor static firing. The thrust and total impulse measured were within 1 percent of the nominal values for the motor.

It can be seen from the torque versus time record that for about the first 10 seconds the motor oscillates in torque about a zero mean. For about the next 16 seconds there is a torque of approximately 2 foot-pounds counterclockwise. After this, a sustained torque of a much greater magnitude occurs, reaching peaks of approximately 12 foot-pounds.

These values, ranging from approximately 8 to 12 foot-pounds, compare with the value of 14 to 18 foot-pounds which were experienced on actual Scout firings. These results demonstrate that the thrust-torque dynamometer is a useful research tool for measuring rocket motor torque if it exists, while, at the same time, accurately measuring thrust.

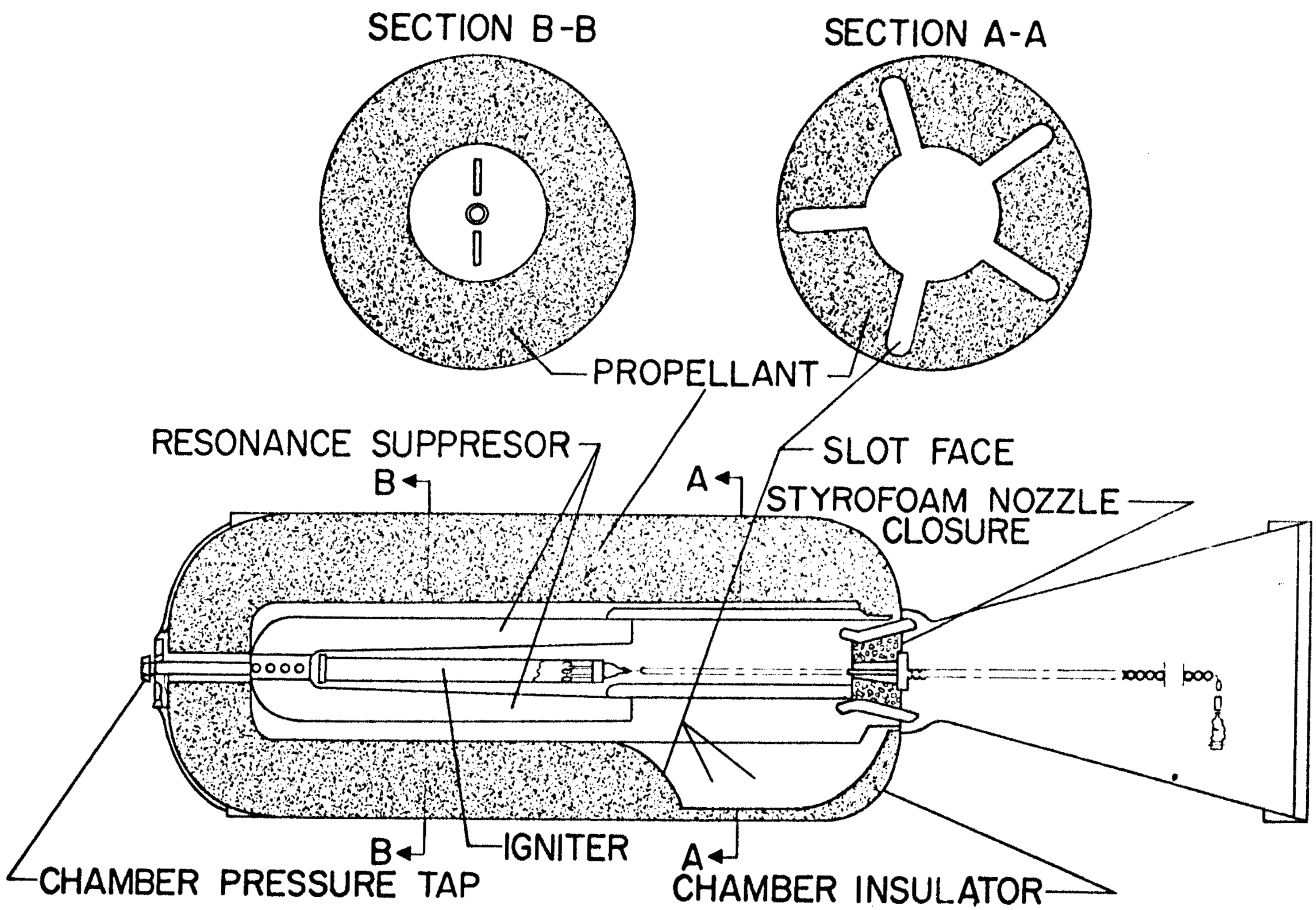

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Figure 1.- Antares X-254, A-1 motor.

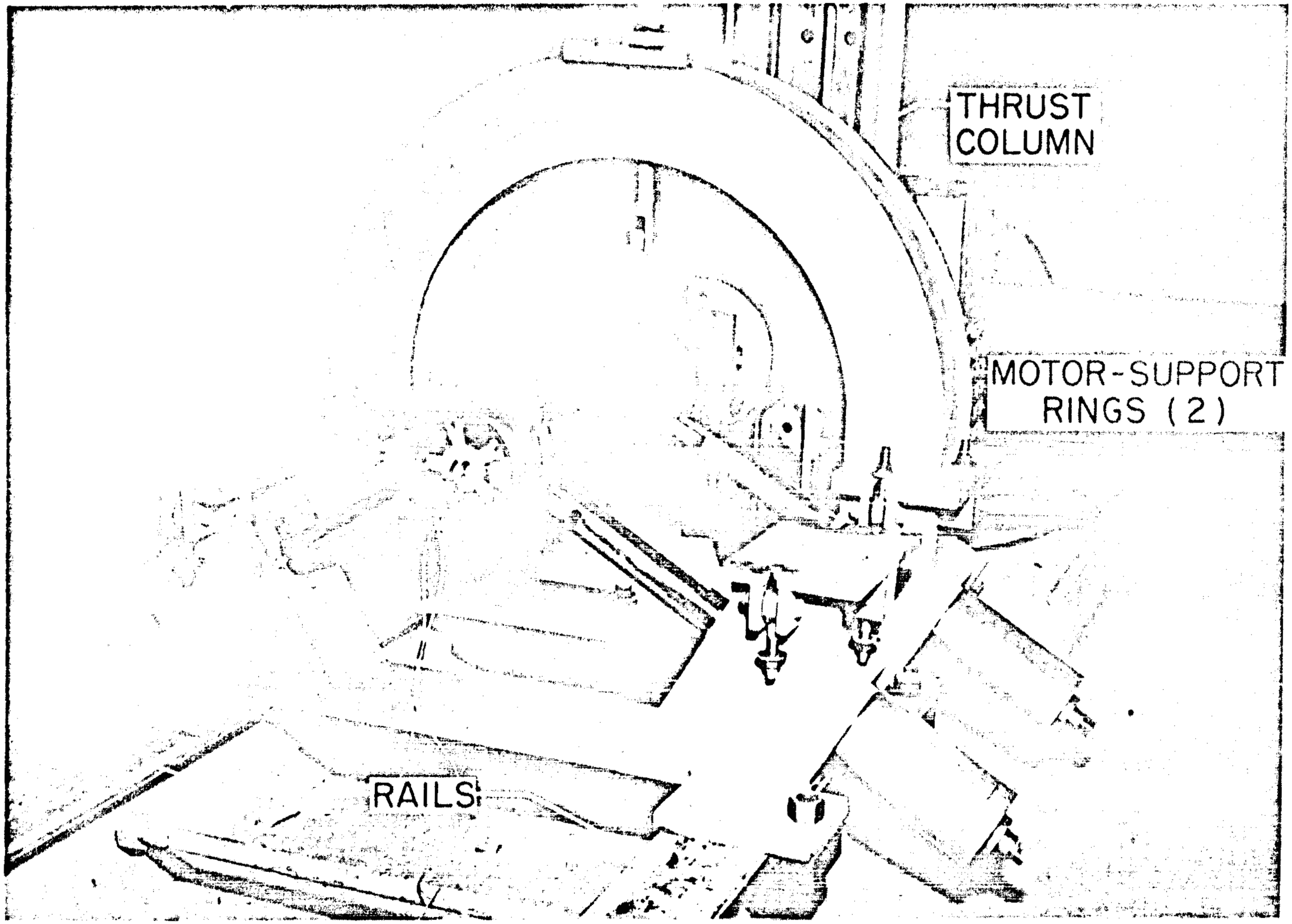

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Figure 2.- Existing thrust stand.

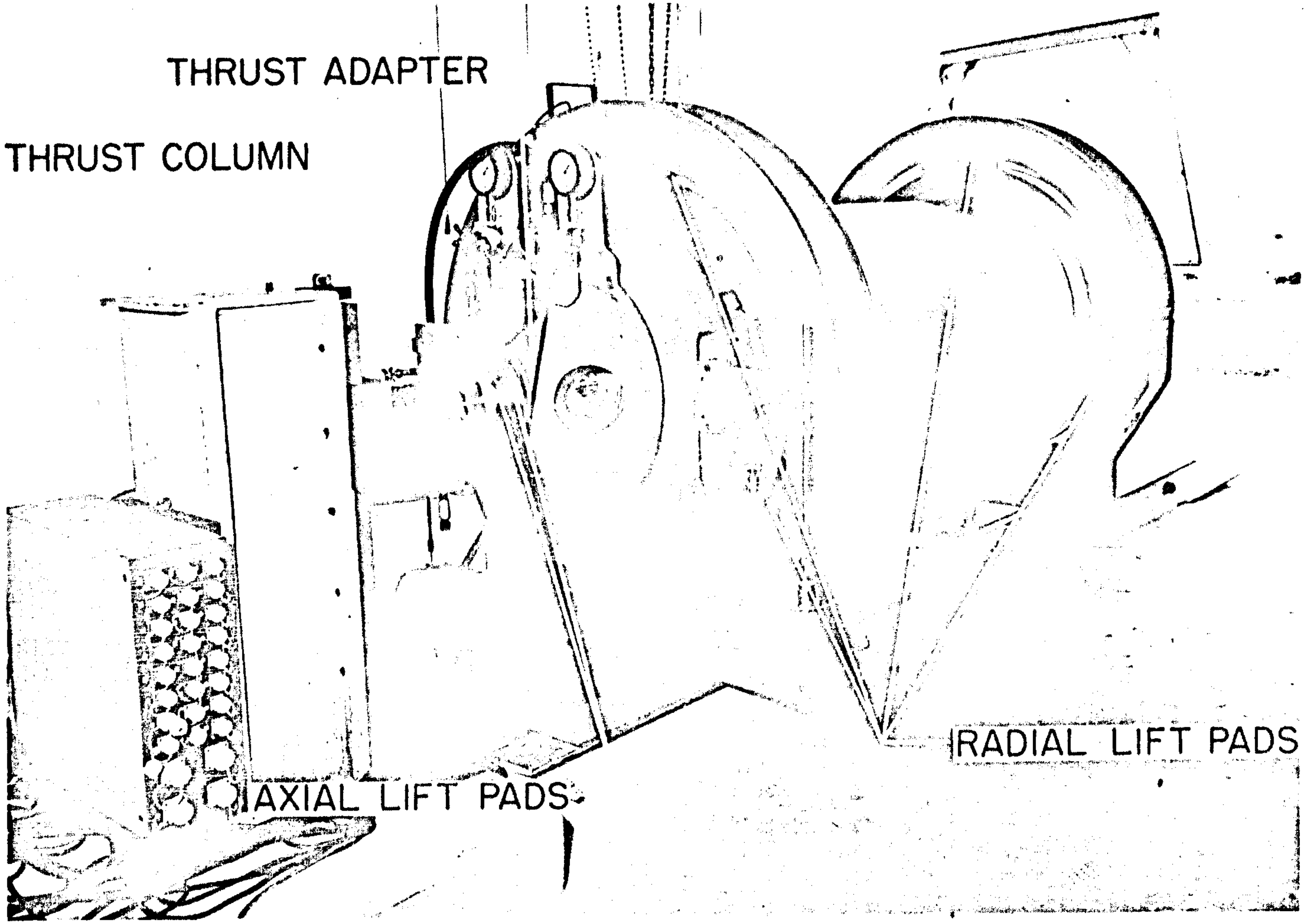

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Figure 3.- Thrust torque dynamometer containing X-254 motor.

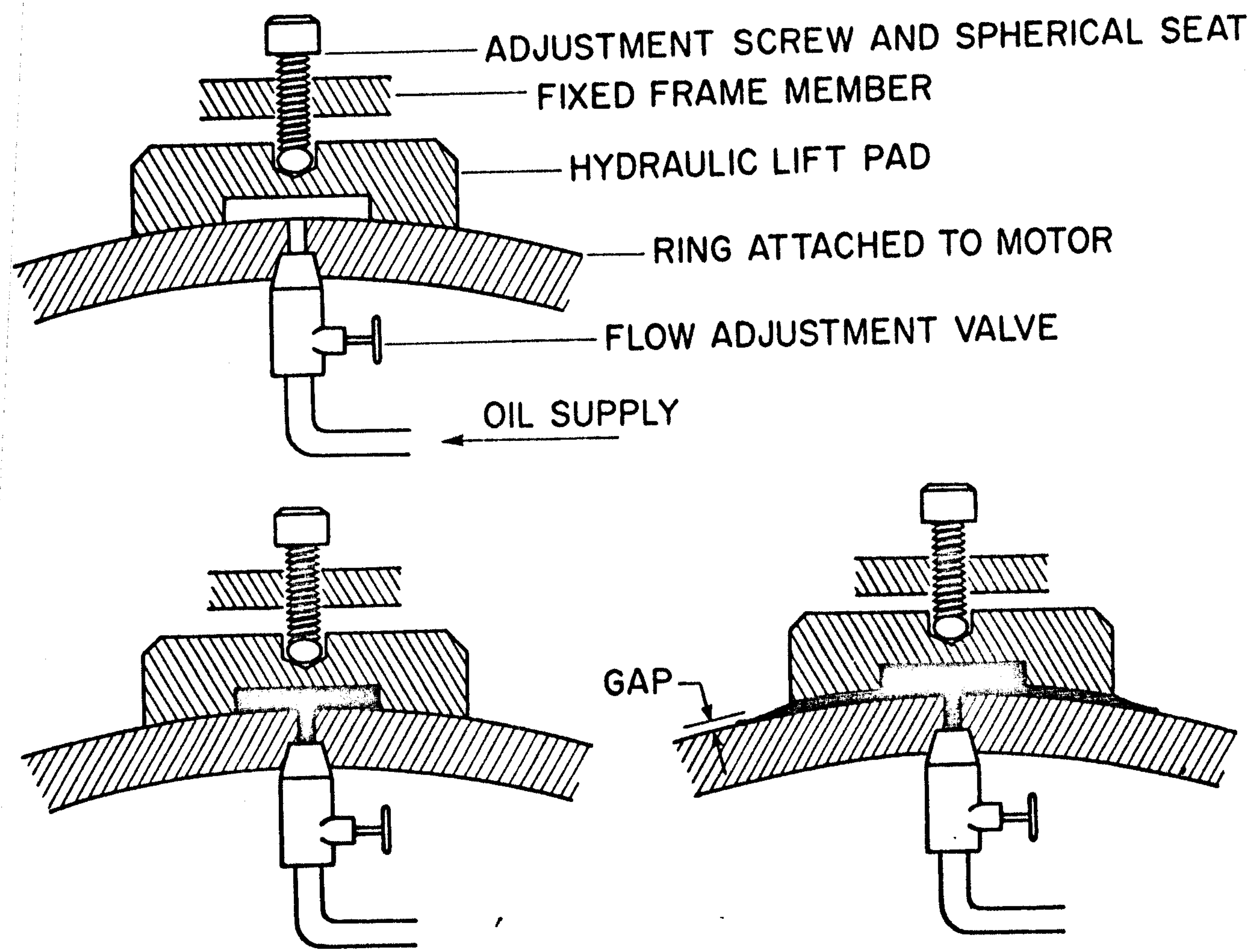

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Figure 4.- Illustration of lift pad operation.

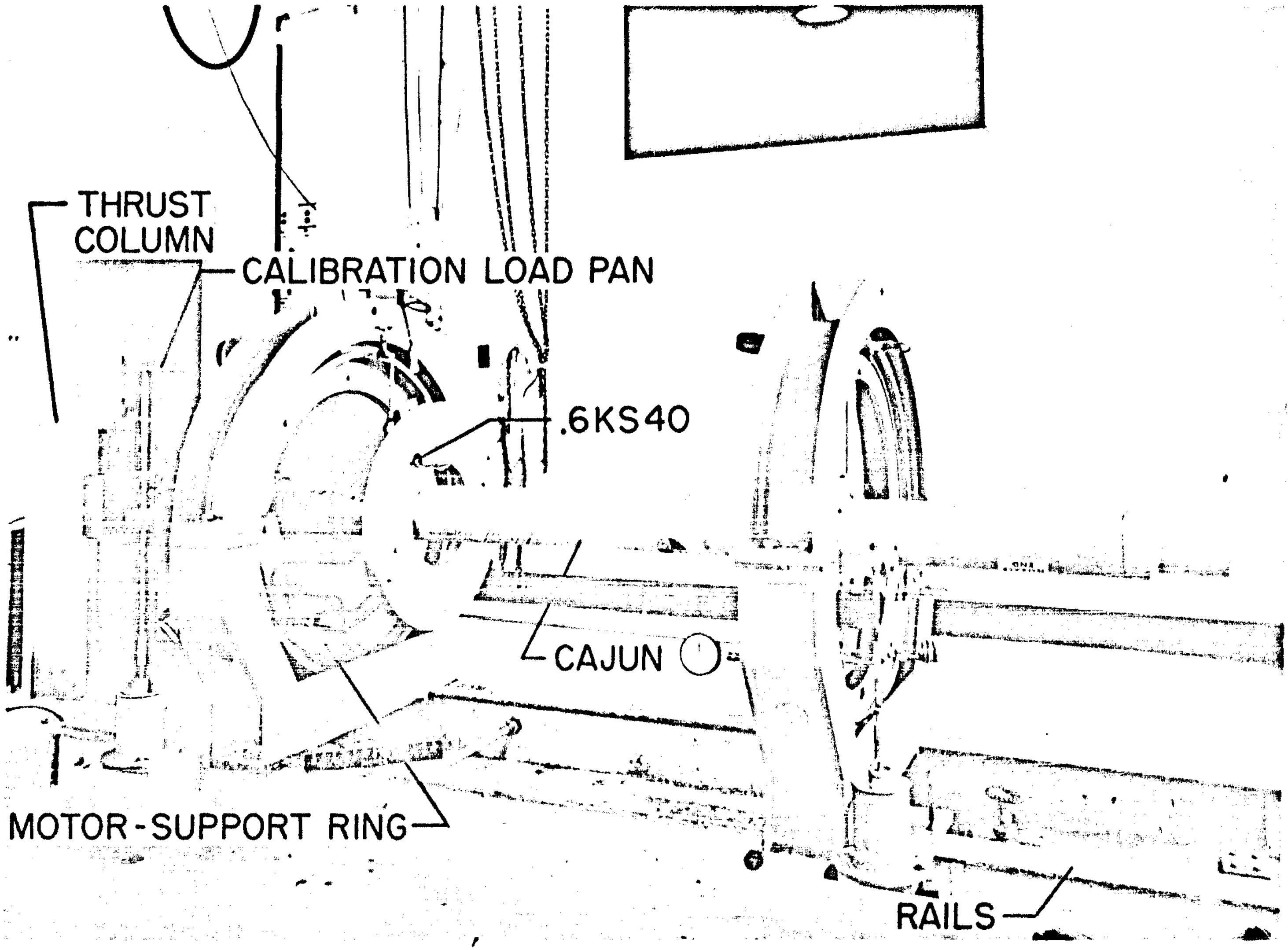

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Figure 5.- Cajun preliminary test.

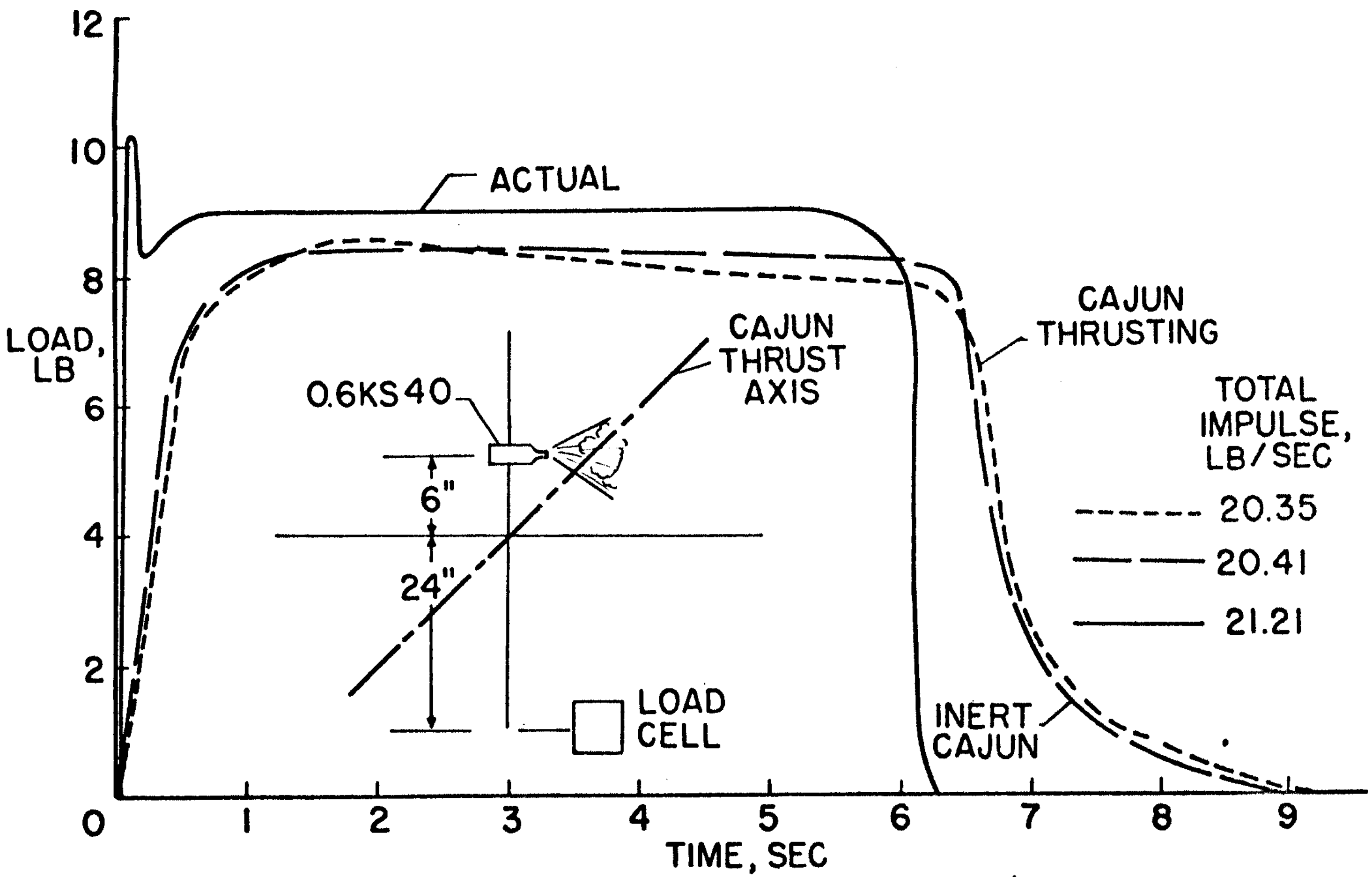

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Figure 6.- Load versus time curve for Cajun test.

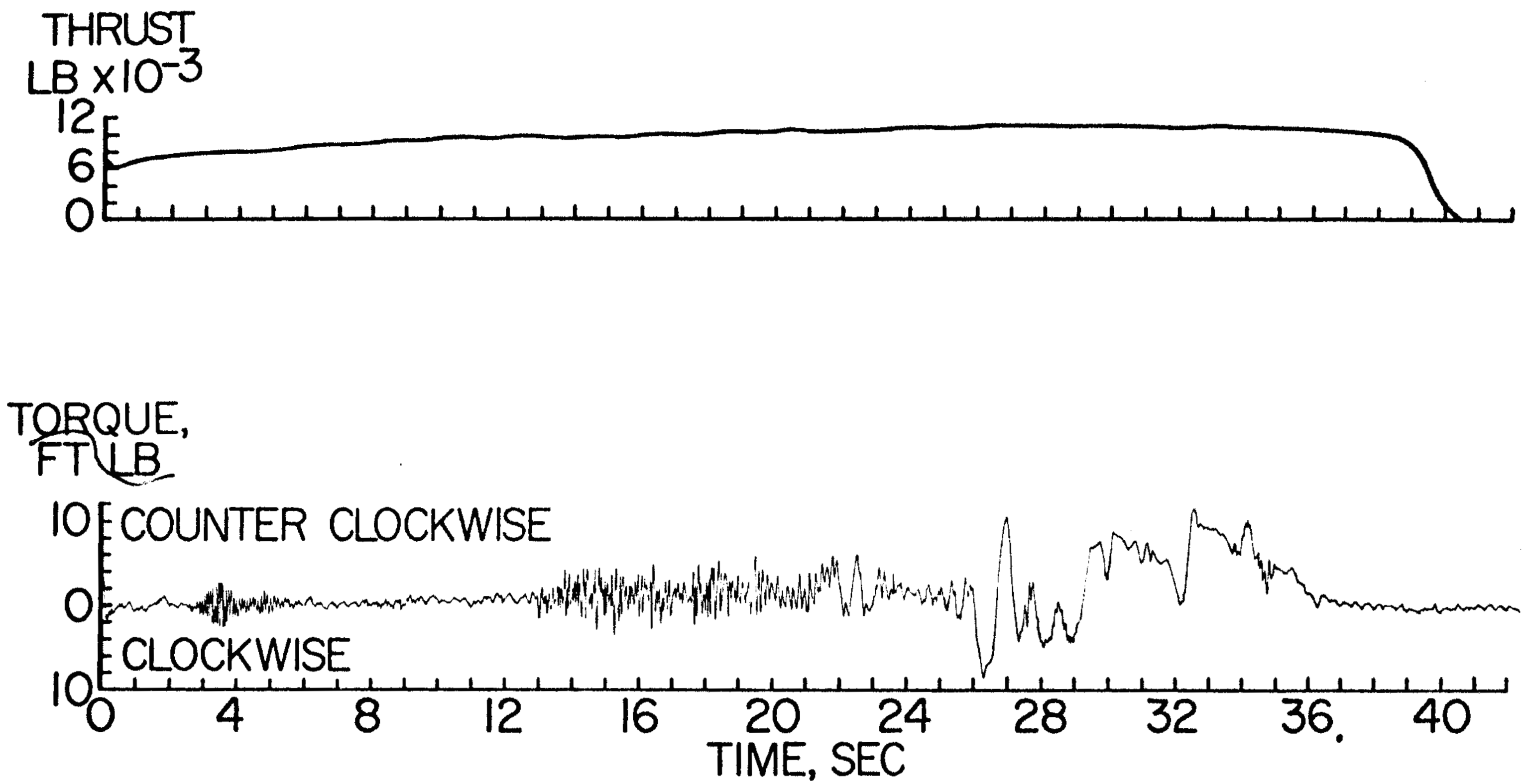

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Figure 7.- Typical thrust-time and torque-time data.